Bridge Deck Membranes

Evaluation And Use In Colorado

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DIVISION OF HIGHWAYS
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HISTORY

Although not aware of it a short three years ago, we were soon to discover we were "babes in the woods" when it came to actually waterproofing bridge deck concrete from intrusion of surface moisture. At that time we were not fully aware of the damage already done to our decks from corrosion of reinforcing steel caused by de-icing salt-laden water. We were possibly lulled into complacency by the fact that a 1967 report made by our research division on the visual examination of 147 bridge decks in the Denver area showed 83 percent of them to be in good-to-excellent condition. Since that time deterioration of bridge decks in the same area has become more noticeable, undoubtedly accelerated by increased use of salt and studded tires.

Colorado was thrust rather abruptly into the waterproofing membrane business by our implementation of FHWA Instructional Memorandum 40-2-70 dated November 10, 1970. Our first specification, in the form of a Special Revision, was drafted in January, 1971. This was strictly a descriptive, rather than a performance specification,

in which was listed by trade name, six products purported to be waterproofing membranes. At that time we had just begun developing something resembling a laboratory evaluation procedure and had done some work with only one of the six products.

In May of 1971, two events took place which were to have decided effects on our membrane program. One, we placed our first membrane system - 1500 sq yds of the single product we had checked in the laboratory - and immediately rejected it from further use due to application problems. Two, the FHWA Region 15 team demonstrated the methods and equipment for the detection of reinforcing steel corrosion and the electrical resistance determination of waterproofing effectiveness of membrane systems.

We immediately obtained the equipment for electrical resistance testing and between laboratory testing and the previously mentioned application problems, eliminated five of the six so-called approved products in our Special Provision. These events, quite naturally, required that we write our second Special Provision for this item. As opposed to our first specification, this second revision was a performance specification with two systems (not trade name products) allowed as alternates. Detailed materials specifications for each system were given as well as application procedures for the membranes and bituminous overlay; the overlay being a special grading, 3/8" inch maximum size aggregate, placed in two lifts. This specification also required final acceptance of the complete system, including overlay, be subject to passing results of electrical resistance tests.

The two systems were (1) the built-up system consisting of five coats of coal tar emulsion with two plies of glass fabric (sometimes referred to as the Massachusetts System) and (2) a prefabricated, reinforced membrane (the specifications for which were admittedly written around the only product we knew anything about at the time). We did, fortunately, have the foresight to include a "substantially equal system" clause which was to prove to be very helpful.

DEVELOPMENT OF LABORATORY EVALUATION PROCEDURE

When it became apparent there was going to be a considerable amount of waterproofing membrane used in Colorado, manufacturers and

suppliers began descending on us like a swarm of locusts. To say we were not fully prepared would be an understatement. Before going further, the relative positions of Colorado's Materials Laboratory and Research Division should be explained. While the two work closely on many projects, they are separate Divisions. The laboratory does not have the budget, manpower or separate facilities to carry out large, formal research projects. Conversely, the Research Division does not have laboratory facilities of its own. An informal program was begun to evaluate and determine laboratory acceptability of the numerous membrane products. This responsibility was placed on two units of the Central Laboratory, the Bituminous Materials Testing Unit and the Flexible Pavement Design Unit. The Bituminous Materials Unit checked many of the claims made by the manufacturer for the components of the products, such as: base composition, reinforcing type and construction, thickness, and certain pliability tests. The Flexible Pavement Unit was assigned the task of developing tests that would indicate how the product would perform under field conditions. Besides being waterproof, we reasoned some of the desirable qualities of a good membrane system should be:

(1) compatability with the primer and bituminous overlay,
(2) thermoplastic at hot bituminous pavement overlay temperature,
(3) ductile enough not to become brittle at low temperatures,
(4) durable enough to withstand damage by equipment required to place bituminous overlay,
(5) practicality of field placement procedures.

We also needed some measurement of the degree of bond between the deck, membrane, and overlay layers, as well as what happened when the hot overlay was rolled (compressed) into the membrane. A review of literature available at that time pertaining to laboratory evaluation of membrane products turned up very little useful information. Out of necessity we developed our own procedure. Our present evaluation procedure (Exhib. 1) which will be discussed more fully later, grew by trial and error from the beginning. Both our evaluation procedure and our present revision of the specifications (Exhib. 2) have been heavily influenced by our field experience over the past three years.

We are not apologizing for our laboratory evaluation procedure. We believe it is practical, if not sophisticated, and has been an excellent starting point for establishing acceptability of membrane systems for field trial. We are well aware that with more time, money, and facilities, more factors could be investigated.

It soon became obvious that in order for our field engineers, as well as the membrane suppliers, to know the evaluation status of various products, we must establish specific requirements for approval of new waterproofing membrane systems. Conditions for approval (Exhib. 3) were written and distributed to manufacturers and suppliers of membrane products. Briefly, they are: (1) the supplier must submit to the laboratory samples of the material, technical data and instructions for application, (2) following a satisfactory laboratory evaluation (with the knowledge that it alone does not constitute full approval) the supplier is allowed to contact contractors having or bidding on highway contracts involving membranes, (3) the contractor, if he desires to use the new product, must obtain written permission for its use from the field engineer who will have obtained the results and recommendations from the laboratory, (4) it will be a trial application on one structure only and the manufacturer or supplier will give the technical assistance necessary to insure the membrane is applied in accordance with their requirements, and (5) having passed the laboratory evaluation and practicality of field application, including pavement overlay, final approval will be subject to the results of Colorado Test Procedure 62 (Exhib. 4) which is the electrical resistance measurement for the waterproofing effectiveness of membrane-pavement systems.

FIELD EXPERIENCE

Field experience over the past three years has affected and in turn been affected by the specifications and laboratory evaluations. It should be noted that except for a few older bridge decks on the interstate system, all of our membranes to date have been placed on new decks, unopened to traffic.

During the 1971 construction season (our first year) we placed membrane systems on fourteen bridge decks. These were all the prefabricated, reinforced type (our System No. 2); three different

brands were used. All were placed by contract and, as might be expected, not without problems. Our specification was quite explicit as to how the membrane and overlay must be placed, but like the ten commandments, it was easier to read than to follow. Of prime concern to us at that time were bubbles in the prime (Fig. 1), bubbles and wrinkles in the membrane (Fig. 2), and placing the overlay without damaging the membrane. We concluded that bubbles in the prime would not be detrimental if only air and moisture vapor were trapped and not volatile material. We also concluded the amount of prime should be kept to a very minimum to help avoid both bubbles and trapped volatiles.

Bubbles and wrinkles in the membrane are a different matter. We have not solved the problem completely and are not aware that anyone else has.

The best solution we have so far is to require that bubbles larger than three inches in diameter be punctured, the air expelled, and patched. Wrinkles are normally a result of poor workmanship (sometimes combined with poor packaging of the membrane rolls) and the temperature of the membrane and deck at time of placement.

Placing the hot bituminous pavement as required by our first performance specification gave us our biggest problem. Vehicles, including mechanical spreaders were not allowed to be operated on the bare membrane unless otherwise permitted in writing. The 1½ inch thick overlay (of 3/8-inch maximum size aggregate) was required to be placed in two approximately equal layers.

This meant that the first 3/4-inch lift had to be placed by hand, end-dumped by a truck backing up, or by a chip-type spreader. All of these methods were tried without much success. We then tried placing the first lift using conventional paving machines, which met with limited success. Finally, placing the full 1½ inches of overlay in one lift with a paving machine was tried and in most cases this proved to be the lesser of evils. The 3/8-inch nominal size mix was still required however, to reduce puncturing of the membrane by large aggregate particles.

During the 1972 construction season, we placed membranes on 48 structures. We used the same specification but realized that once we had accumulated enough experience, we would have to revise it again.

Eleven structures in 1972 were covered with our System No. 1, the built-up coal tar emulsion-fiberglass system (Fig. 3). A total of twenty prefabricated membranes of two different brands were placed (Fig. 4), and; under our "Substantially Equal System" clause, seventeen decks were waterproofed with a single component hot applied, polyvinyl chloride base elastomeric membrane. This was the first such use of the product which, up to that time, had been used quite successfully only as a crack and joint filler. The credit for suggesting this material for use as a deck waterproofing membrane must be given to a local Denver Contractor whose specialty is concrete sawing and joint sealing. He had used this material and was familiar with its performance as a joint sealer. He was also among the first applicators of the prefabricated membrane system in Colorado and therefore was in a position to see the possibilities of using this sealer as membrane. Our laboratory did considerable work with this material, evaluating the bond, shear, compatibility with bituminous overlay as well as waterproofness. We agreed it was worth a field trial.

Naturally there were application problems to be solved. The problems were different, but no more difficult than problems with the other systems. With the proper equipment, the material can be sprayed (Fig. 5). However, it was soon discovered that, by using the proper technique, a more uniform application, practically free of pinholes and bubbles could be accomplished by the squeegee method (Fig. 6). A contractor's primary interest in using this type of system, instead of others, is its relative ease of application and the fact that it can be paved over immediately.

During 1972 we had been occasionally rechecking the waterproofing effectiveness of some membraned decks which had been in service for six months or more. A number were showing leaks, especially in the wheel tracks. Failures were occurring in all systems and brands

which had been used. It was speculated that under heavy traffic and high summer temperatures the membranes were thinning out or migrating away from the wheel tracks. A thicker bituminous overlay ($2\frac{1}{2}$ or 3 inches) could be of some help in distributing the weight and preventing this migration, but it seemed to us that it would be only a delaying action. Also, the probability of requiring structural changes in the bridge design had to be considered. No doubt, the idea of using a protective layer between the membrane and bituminous overlay did not originate with us. But gradually it became obvious that such a layer was needed. Late in 1972 and early 1973 we began investigating and evaluating in the laboratory a number of products which might offer this protection.

We first investigated the use of the asphalt plank type of protection board commonly used over waterproofing membranes on railroad bridge construction. When not subjected to heat, this type of panel is a very tough, puncture resistant material. We discovered however, that at temperatures representing those of paving operations, the air blown asphalt core became very liquid and the small amount of mineral filler and fiberglass offered practically no resistance to puncturing by the aggregate. There is little doubt a panel could be, or possibly is, manufactured which would have the high temperature, puncture resistant qualities which are desirable, but there were none readily available to us at that time.

We needed a product that was commercially available in larger quantities without delay. We decided to try asphalt roll roofing and after evaluating practically all weights and grades available, found that the 65 lb grade (meeting ASTM D 224 Specifications) was most puncture resistant and provided the best bond to the hot overlay as well as to all of the membranes with which it was tested. Fortunately, asphalt roll roofing seems to possess the right combination of asphalt type, felt and mineral matter to offer the protection we needed and which was lacking in the protection panels.

One other important benefit was gained by the use of the roll roofing in that the requirement of special grading, 3/8-inch maximum size bituminous overlay was no longer necessary. Because of the

small quantities involved, we had been paying up to three times as much for the special grading as our regular 3/4-inch maximum size mixes. In most cases a net saving could be realized by using the roofing and 3/4-inch mix.

The experience gained in field application during 1972, the development of a hot applied liquid membrane, and the decision to require asphalt roll roofing over all membranes, resulted in another complete rewriting of our specification.

CURRENT METHODS AND SPECIFICATIONS

During 1973, membranes were placed on 40 structures. Essentially, our current specification was used for 33 of these. On seven decks, which were holdover from 1972, the coal tar emulsion system was placed under the previous specification which did not require roll roofing. Only four decks had prefabricated membranes; two different brands were used. Hot liquid membrane was applied to 29 structures. Four of the 29 were a new rubberized asphalt product which appears to make a satisfactory membrane.

Applying the roll roofing over membranes has not presented any particular problem since proper application technique was developed. The material rolls out and lays surprisingly flat; especially in warm weather. Two methods are commonly used: (1) The entire thirty foot roll is unrolled at one time directly onto the membrane (Fig. 7). (2) Shorter sections are cut so two men can place one edge directly against a previously laid section (Fig. 8). Our specifications allow a maximum 3/8-inch gap between sheets and states that overlap shall be kept to a minimum, with a maximum of 4 inches allowed.

We require a compatible mastic to be used (if necessary) only in the amount required to hold the roofing in place until it is paved over. The roll roofing appears to be providing very satisfactory protection to the membrane from damage by construction equipment (Figs. 9 and 10). By all indications so far, it is also resisting puncture by the aggregate as we had expected.

Our laboratory evaluation procedure, like our specification, has undergone numerous changes. The present procedure is reported in detail in the accompanying Exhib. 1. It is briefly summarized as

follows (Figs. 11 through 18):

An 8 x 12 x 2 inch concrete slab, which may have reinforcing steel bars cast into it (although not absolutely necessary) is prepared with primer and membrane in accordance with the manufacturer's recommendations. At this point, the membrane covered slab may be tested for waterproofness using electrical resistance. However, acceptance or rejection is not determined at this point. The roll roofing is then applied using a mastic to hold it in place, if necessary. Two 4-inch diameter by 1½ inches high, dense graded bituminous specimens are molded at 275 F in a split ring mold. Initial densification is accomplished in a kneading compactor. The mold is then quickly transferred to the prepared slab and two quick static loads of 200 psi are applied.

The story behind this molding procedure is rather lengthy, but it suffices to say that it was the only way we could approximate both mixture density and rolling pressure of field application. When the specimens are cool, water (containing a wetting agent) is applied to one specimen until free water is observed at the contact of the specimen and membrane. The previously water-saturated slab is placed in a shallow metal pan of water and the electrical resistance checked through the saturated bituminous specimen. The ground contact can be made either to the reinforcing steel or to the metal pan.

The test for bonding effectiveness of the second specimen is preformed by standing the concrete slab on one side and placing a semi-circular metal bearing plate over the specimen. The assembly is then placed in the compression machine and a steady load is applied at the rate of 0.25 in. per minute until failure occurs.

We believe that a visual examination of where and how the bond failure takes place is equally as important as the force necessary for failure. In addition to examining the sheared specimen, the other specimen is sawed in half through the concrete slab, using a diamond blade saw. This enables a close examination of the complete undisturbed system.

We have performed this evaluation on twenty or more products. However, because of changes in the procedure and the addition of roll

roofing, many products have been tested numerous times. The total number of evaluations would be well over one hundred.

Six products have been given full approval for continued use based on both laboratory and actual field results. Two additional products have laboratory approval, but have not been used in the field yet.

FHWA Informational Memorandum 40-2-72 issued in November, 1972 (superceding the 1970 IM) caused Colorado to review its entire bridge deck waterproofing program. Beginning in 1971, we had been placing membranes on all new decks, regardless of their location in the state. Among other things, this latest IM states that with very good documentation on the use of de-icing salts, we may be selective as to which structures are to receive membranes. Colorado made a salt usage survey and received permission from the FHWA Division Engineer to delete membranes in rural areas where practically no salt is used. Membranes will now be used mostly in the more heavily populated urban areas where a clear pavement policy is in effect.

Table I shows the total number and type of membrane systems placed to date in Colorado as well as the brand names of each system.

TABLE I

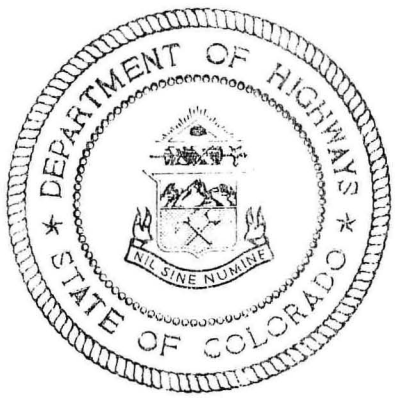
Colo. System	Type	No. Brands	No. Placed
1	Built-up coal tar emulsion	1	18
2	Prefabricated rolls	3	38
3	Hot applied liquid	2	46
	Total Number Membrane Systems Placed		102

As previously mentioned, some informal follow-up electrical resistance testing had been done on older membrane systems. This past summer it was agreed that to adequately monitor the performance of the different systems and brands (with and without the roll roofing) a formal, scheduled program of retesting must be accomplished. Neither the Central Laboratory nor the Research Division were in a position to do this statewide monitoring without help. Since each of our six widely scattered districts now have the required electrical resistance equipment, their help was solicited in performing this task.

Fifteen structures, representing each system and brand of membrane, were selected to be retested at six month intervals. A form to report both the first test and subsequent follow-up testing has been devised (Exhib. 5). The first follow-up reports are now coming in, but it will probably be a year before much useful information will be accumulated.

To summarize, it appears that we will be requiring membranes on fewer structures under our present policy. However, we will continue to try to improve our knowledge through laboratory testing, field experience, and communication with other agencies.

We are also aware of the considerable amount of research being conducted toward methods other than membranes for the protection of deck concrete from deterioration. Someday one of these methods may make membranes obsolete. In the meantime, we are working to achieve the best possible results under the guidelines spelled out in FHWA IM 40-2-72.



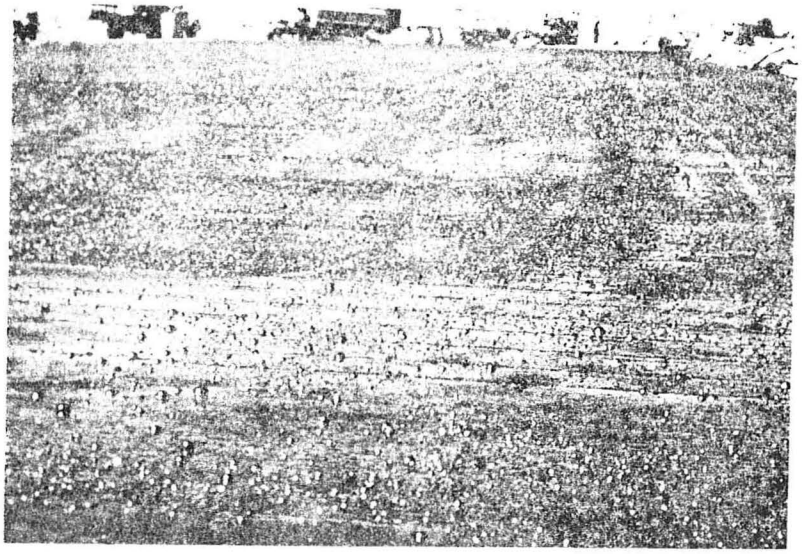


FIGURE 1

Bubbles develop in certain volatile materials used as prime coat with the prefabricated membranes.

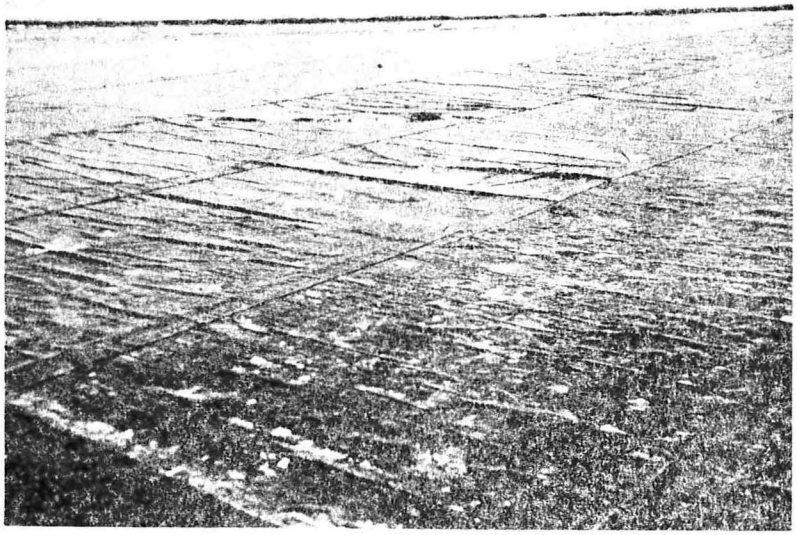


FIGURE 2

Bubbles in prefabricated membrane caused by the expansion of trapped volatiles in the prime coat. Wrinkles due to improper packaging of membrane.

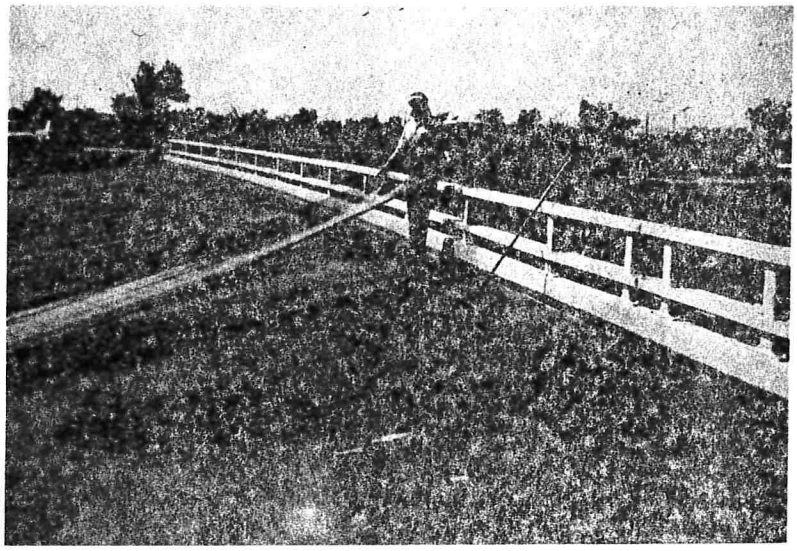


FIGURE 3

Placing coated glass fabric in built-up coal tar emulsion membrane. This is Colorado System No. 1.

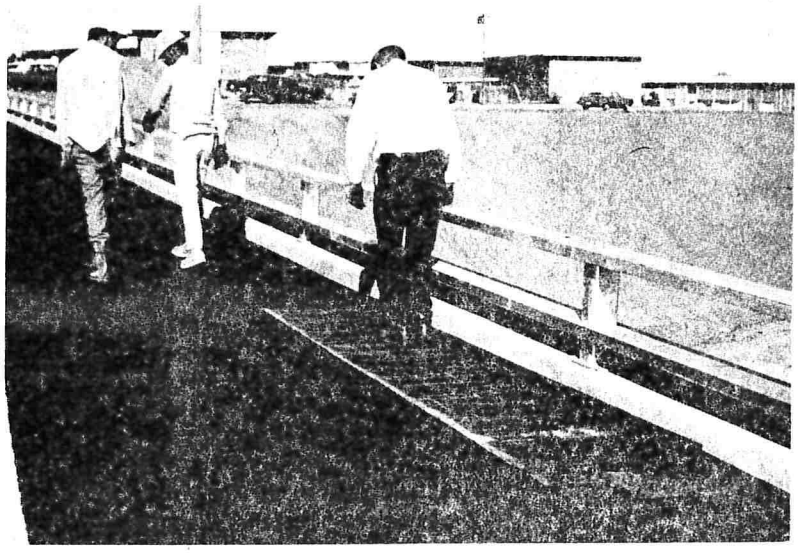


FIGURE 4

Placement of prefabricated membrane on primed deck and curb. Note that the prime has cured tack-free prior to placement. This is Colorado System No. 2.

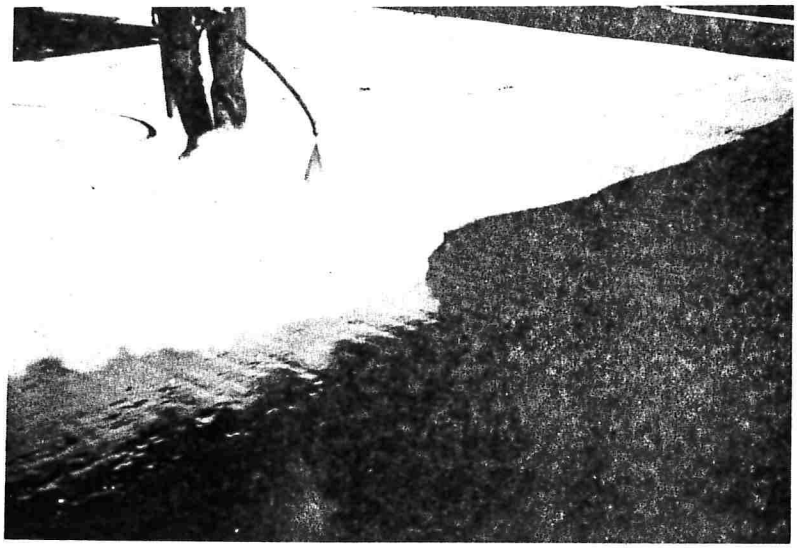


FIGURE 5

Applying hot, liquid elastomeric membrane using a pressure spray. Note difficulty the operator has seeing application point. Colorado System No. 3.

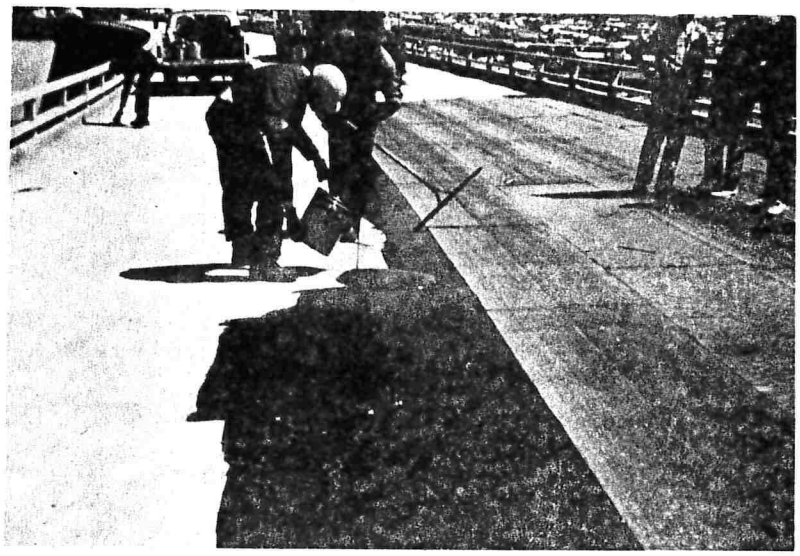


FIGURE 6

Applying hot, liquid elastomeric membrane by pouring and spreading with a squeegee. Note absence of smoke. This is Colorado Membrane System No. 3.

FIGURE 7

Placing 65 pound grade asphalt roll roofing by unrolling the entire 30 foot roll. This method not recommended for decks with horizontal curvature.

FIGURE 8

Placing 65 lb grade asphalt roll roofing in approximately 10 ft sections. Butting adjacent sections without gaps or overlaps is more easily accomplished.

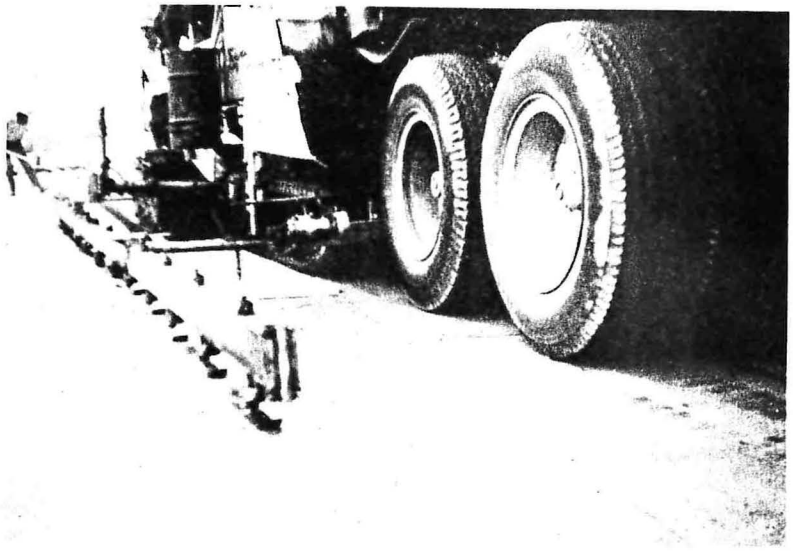


FIGURE 9

Placing 1-1/2 inches of 3/4 inch maximum size hot bituminous pavement over 65 pound grade asphalt roll roofing using conventional paving equipment.

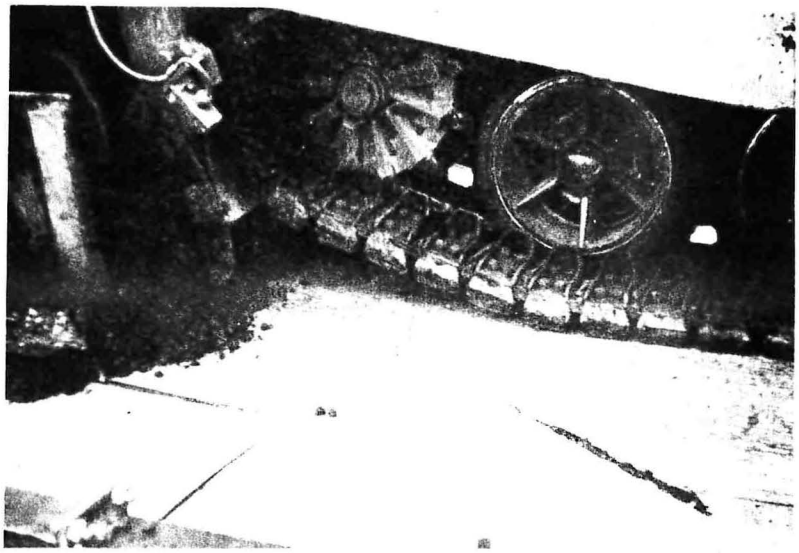


FIGURE 10

Careful operation of conventional paving equipment causes no tearing or displacement of the 65 pound grade asphalt roll roofing or bridge deck membrane.

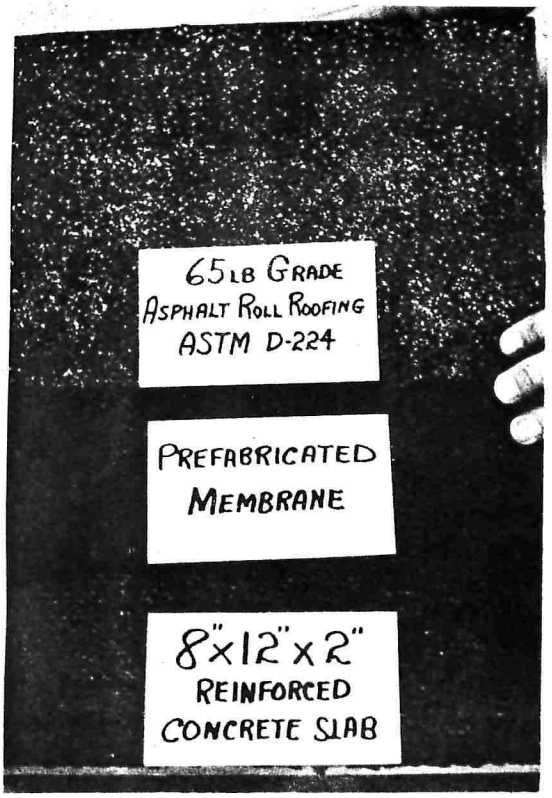


FIGURE 11
Typical membrane system components used for Laboratory test specimens.

FIGURE 12
Hot mix at 275 F being placed in preheated split ring mold held by the kneader compactor mold holder.

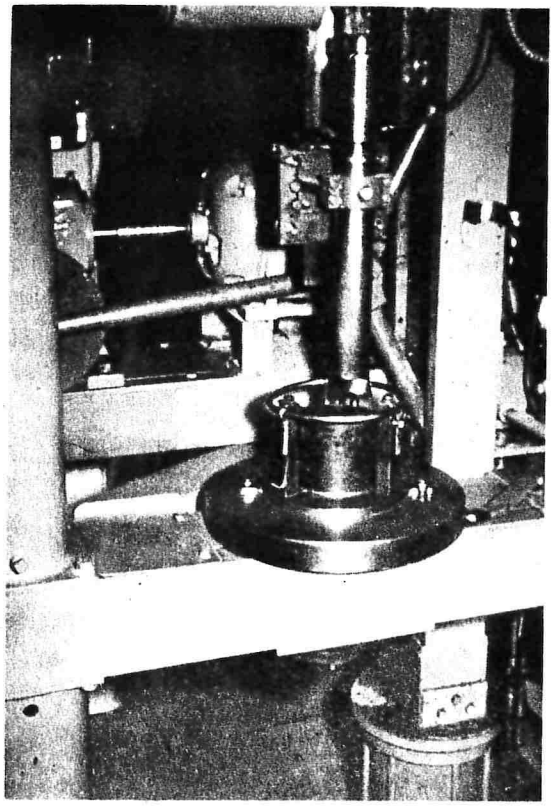


FIGURE 13
Initial densification is achieved by using 20 tamps in the kneader compactor at 250 psi foot pressure.

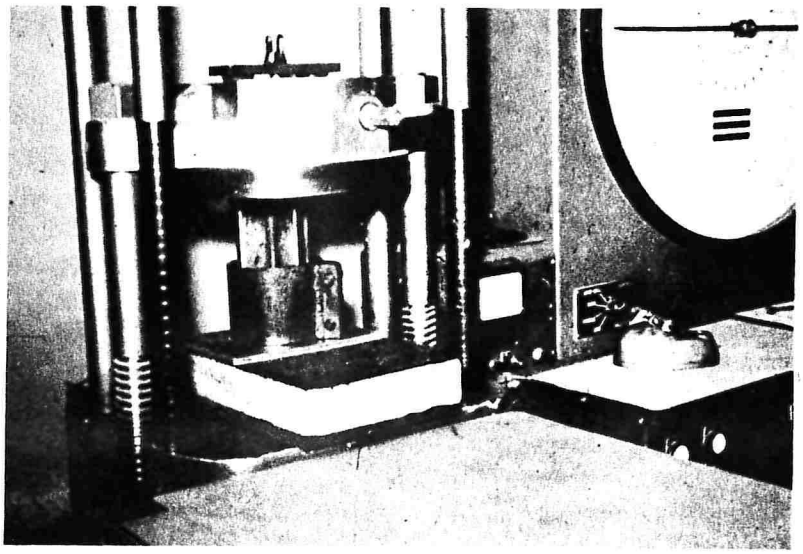


FIGURE 14
Hot specimen is compressed onto membrane system using two individual loadings at 200 psi static pressure each. Note metal template on roofing.

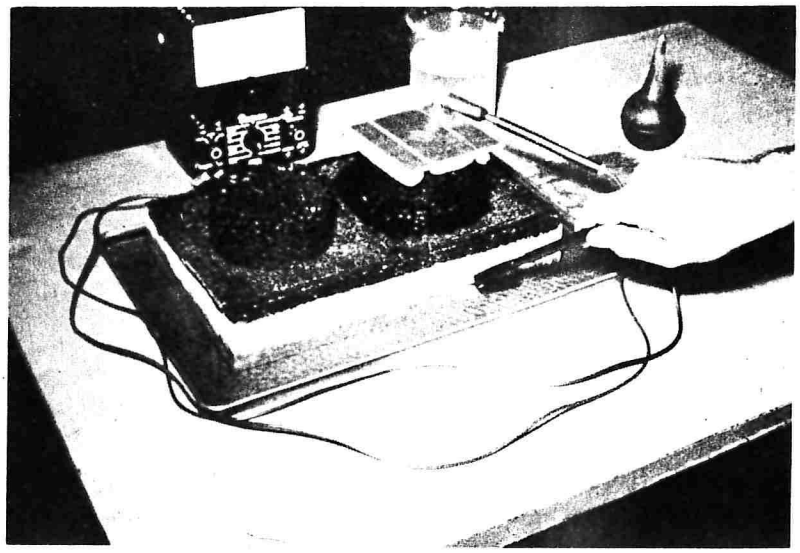


FIGURE 15

Electrical resistance test being performed on saturated bituminous specimen molded on membrane system.

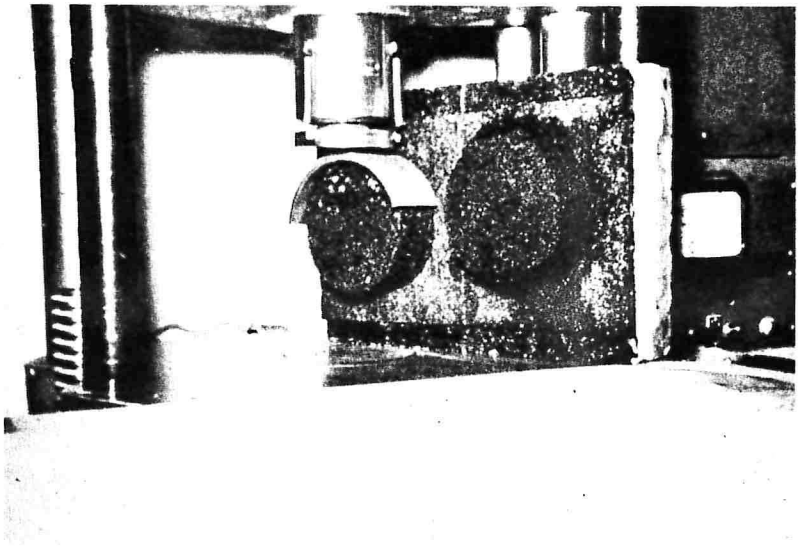


FIGURE 16

Test underway for bonding effectiveness by direct shear. Compression machine travel is 0.25 in/min.

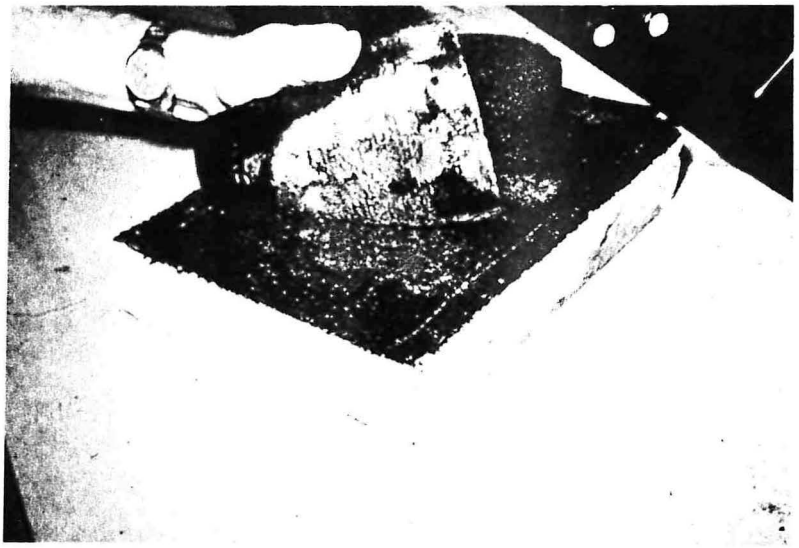


FIGURE 17

Examination of membrane system after completion of bond test noting where and how the failure occurred.

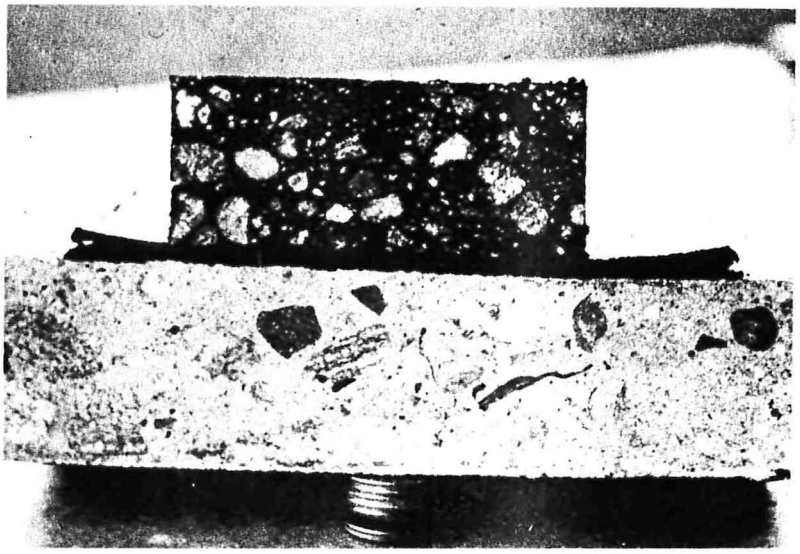


FIGURE 18

Examination of sawed specimen after electrical resistance test. Note the thermoplastic bonding.

EXHIBIT 1

COLORADO DIVISION OF HIGHWAYS

LABORATORY EVALUATION PROCEDURE FOR BRIDGE DECK WATERPROOFING MEMBRANE SYSTEMS

SCOPE

1.1 This procedure describes the laboratory method for evaluating waterproofing membrane systems proposed for use under the revision of Section 515 of the Standard Specifications.

SUBMITTING SAMPLES FOR EVALUATION

2.1 The manufacturer shall submit to the Division of Highways Materials Laboratory, 4340 East Louisiana Avenue, Denver, Colorado 80222, the following:

A. Technical data on primer and membrane for prefabricated systems or components of fabricated in-place systems, including composition, thickness, test methods, and results.

B. Instructions for application of primer and membrane or components including rate of primer application, length of curing, recommended temperatures for placing membrane on the deck and temperature of asphaltic pavement when placed on membrane.

C. A one quart sample of primer and a sample of the membrane measuring a minimum of 12 in. by 48 in. or a sufficient quantity of components for fabricated in-place systems to make 4 sq. ft.

PROCEDURE

3.1 Samples of individual components of a system, including primer, reinforcement, and prefabricated laminated sheets, may be tested for any of the specifications claimed by the manufacturer. They also may be tested for specification requirements of the current revision of Section 515.

3.2 Laboratory specimens of the complete membrane system, including 65 lb. roll roofing and Hot Bituminous Pavement overlay, shall be formed on concrete slabs as follows:

3.2.1 Concrete slabs, 8 in. x 12 in. x 2 in., shall be cast with one or two No. 4 reinforcing steel bars placed in the center one-third of the 12 in. dimension. The steel shall be placed in such a manner so as to allow one end to be exposed upon removal of the slab from the form. The surface of the slab should receive the type of finish required for bridge decks on which a membrane is to be applied. The slabs shall be cured under ideal conditions for a minimum of 7 days.

3.2.2 Following curing, a dry slab shall be prepared in strict

accordance with the manufacturer's recommendations, including rates of application of primer and components, temperatures, and curing.

3.2.3 At this time (before application of the hot bituminous pavement specimens) the membrane may be tested for waterproofing effectiveness by the electrical resistance method described in Section 5.1.

3.2.4 65 lb. grade Asphalt Roll Roofing conforming to ASTM D 224 shall be applied over the membrane. If required, a compatible mastic, supplied by the manufacturer shall be used to hold the roll roofing in place on the membrane. The dimensions of the roofing should be slightly smaller than the 8 x 12 in. concrete slab and centered to prevent any overhang.

3.2.5 Two 4-in. diameter by 1½-in. high grading E Hot Bituminous Pavement specimens shall be formed on the prepared slab in the following manner:

Place a 4 in. diameter by 4 in. high (minimum) steel, split ring mold in the kneading compactor mold holder apparatus. The mold and holder shall be pre-heated to 275 F and a light film of oil wiped on the inside surface. Deposit 680 g of Grading E Bituminous Mix at 275 F into the mold and rod approximately 20 times with a 3/8-inch diameter pre-heated rod. Apply 20 tamps at 250 psi with the kneader compactor. Immediately transfer the mold and mix to the prepared slab on which a metal template, 6in. x 8 in. x 1/4 in. having a 4-1/4 in. diameter hole, has been placed. Carefully center the split ring mold over the template hole and place a preheated follower on top of the specimen. Slide this assembly into the compression machine and apply two quick 200 psi static loads, releasing the pressure to zero between loads. Release the pressure and slide the slab out from under the compression machine head. Remove the steel follower, place a wooden block across the top of the mold and slide the slab and assembly back under the compression machine head. Apply approximately 200 lbs total pressure and release tension on the bolts of the split ring mold, allowing the mold to open about 3/8 in. Release the compression machine pressure, remove slab, and carefully remove mold from specimen. It may be necessary to place the steel follower on top of the specimen and hold it by hand while removing the mold in order not to disturb the specimen. Mold the second specimen on the membrane in the same manner as the first and allow both to cool to room temperature.

TEST FOR BOND

4.1 The bonding effectiveness of the complete membrane system shall be determined by subjecting one of the molded bituminous specimens to a direct shearing force parallel to the surface of the membrane.

4.1.1 Stand the concrete slab on one side. Place a 1-1/2 in. wide, semi-circular steel plate, having at least a 2 in. radius, on

top of the specimen to be sheared. Slide the assembly into position in the compression machine fitted with a small diameter swivel head. Align the specimen so that the swivel head is as close as possible to the semicircular plate without touching it. Apply a steady load at approximately 0.25 in. per minute until failure occurs. It may be desirable to continue pressing after failure to observe the type of bond and exactly where the failure occurred. Record the total number of pounds at failure as the force necessary to shear the weakest portion of the membrane system. This may occur between the concrete slab and membrane, between the membrane and bottom of the asphaltic pavement specimen, or in the pavement specimen.

TEST FOR WATERPROOFING EFFECTIVENESS

5.1 Saturate the second prepared specimen by slowly applying water to the top surface until free water is observed seeping from the bottom of the specimen close to the membrane. A small amount of wetting agent in the water will facilitate this process. In case the specimen does not readily absorb the water, it may be necessary to build a dam around the outside of the specimen. This may be accomplished by using a strip of heavy waxed paper, held in place with rubber bands, and sealing the contact of the paper and specimen with catalytically blown asphalt diluted to a thick paint consistency with a volatile solvent. After thorough saturation of the specimen, test for electrical resistance as follows:

A. Attach a 2-3/4 in. square by 1/2 in. thick piece of polyurethane sponge to a 2-3/4 in. square by 1/8 in. (11 gauge) aluminum plate with rubber bands.

B. Thoroughly wet the sponge and place on top of the saturated specimen.

C. Connect the positive lead of an ohmmeter (20,000 ohm per volt rating) to the aluminum plate and make good contact with the negative lead to the exposed reinforcing steel in the concrete slab.

D. Set the ohmmeter to the highest resistance setting and read the ohms resistance.

E. Do not allow water which has seeped through the specimen to run over the edge of the membrane onto the reinforcing steel.

Note - It may be desirable to place the concrete slab in a pan containing about 1/2 in. of water to be certain the slab contains moisture prior to testing.

VISUAL EVALUATION

6.1 The visual evaluation of the complete membrane system should include (1) an examination of where and how the shear failure took place. This is as important as the actual number of pounds

required for failure. A system having a high resistance to shear but lacking elasticity may not be as effective as one having less resistance but more integrity. (2) Using a diamond blade saw, cut through the second specimen, and concrete block. Examine the contact for resistance to puncture by the aggregate and integrity of the membrane to resist displacement.

EVALUATION CRITERIA

7.1 Resistance to shear - No absolute minimum value of total pounds of force required to shear the specimen can be stated for the reasons given in Section 6.1. However, any system producing a total shear of less than 100 lbs should be analyzed thoroughly.

7.2 Waterproofing effectiveness - The minimum ohms resistance allowed by the revision of Section 515 of the Standard Specifications is 500,000 ohms when testing completed membrane-pavement systems in the field. This would also be the minimum acceptable for laboratory specimens. However, any laboratory specimen having an electrical resistance of less than one million ohms should be considered suspect and be investigated thoroughly.

7.3 A successful laboratory evaluation alone does not constitute approval of the complete membrane-pavement system. Final approval will be subject to the results of Colorado Test Procedure 62 and the Engineer's evaluation of the practicality of construction techniques.

EXHIBIT 2

September 10, 1973

REVISION OF SECTION 515
WATERPROOFING MEMBRANE

Section 515 of the Standard Specifications is hereby revised to include the following:

DESCRIPTION

This work shall consist of furnishing and placing approved waterproofing membranes and protective covering over a properly prepared concrete bridge deck prior to placing the Hot Bituminous Pavement (HBP) overlay, in accordance with these specifications, and in reasonably close conformity with the plans or as ordered.

The waterproofing membrane shall consist of one of the following described systems:

System No. 1 - A primer, 5 coats of coal tar emulsion and 2 plies of coated glass fabric.

System No. 2 - A primer and prefabricated, reinforced membrane.

System No. 3 - A primer, if required, and a single component, hot applied, elastomeric membrane.

NOTE: - Upon written application to, and written approval from the Engineer, and upon conditional approval from the Central Laboratory, a substantially equal system may be substituted for any of the above systems.

MATERIALS

Protective Covering

Unless otherwise directed, all membrane systems shall be covered with 65 lb grade Asphalt Roll Roofing conforming to ASTM D 224.

Membrane System No. 1

Coal Tar Primer

Coal tar primer shall be produced from coal tar pitch blended with a solvent. The coat tar pitch shall conform to the requirements of Federal Specification R-C-1424. Petroleum tars and oil and water gas tars shall not be used. The coal tar primer shall conform to the following requirements:

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WATERPROOFING MEMBRANE

Determination	Test Method	Requirement
Weight per gallon at 25° C., pounds	ASTM D 1010	8-10
Stormer Viscosity Krebs Units	Federal Test Method Standard No. 141, Method 4281	50-60
Distillation to 235° C., percent by weight	ASTM D 20	48-55
Drying time nominal room temp., 400-500 sq. ft. per gal.,	ASTM D 1010	
Dry to touch, max.		1 hour
Firm dry, max.		2 hours

Coal Tar Emulsion

Coal Tar Emulsion shall conform to the requirements of Federal Specifications R-P-355, "Pitch, Coal Tar Emulsion (Coating for Bituminous Pavements)" with the following modifications and requirements:

1. In the determination of ash of nonvolatiles in accordance with the requirements of ASTM D 1010 the dry residue shall be thoroughly crushed before ignition.

2. The test for resistance to impact will not be required.

3. The coal tar emulsion shall not be fortified with antifreeze.

4. The coal tar emulsion shall be shipped in containers of a size not exceeding 55 gallons.

Coated Glass Fabric

Coated glass fabric shall conform to the requirements of ASTM D 1668 for woven glass fabric treated with coal tar pitch.

Membrane System No. 2

Primer

The primer used to bond membrane to deck and to seal seams and patches shall be a water resistant adhesive compatible with the

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REVISION OF SECTION 515
WATERPROOFING MEMBRANE

membrane. The primer shall be of suitable consistency for application by brush, roller or spray without further dilution.

Membrane

The membrane shall be factory laminated sheet composed of either suitably plasticized coal tar, rubberized asphalt, bituminous mastic or similar compounds reinforced with synthetic or fiberglass fabric. It shall be uniformly well manufactured free from blemishes and discontinuities and other defects. The membrane shall be supplied in rolls, having a minimum width of 36 inches, and shall conform to the following requirements:

Thickness:	70 mils minimum
Pliability (1)	No cracks

(1) Place a 4 in. by 1 in. membrane specimen in a + 10°F cold chamber for two hours. While still in the cold chamber bend the specimen 180° over a one inch mandrel. Remove specimen from cold chamber and inspect for cracks.

Membrane System No. 3

Primer

When required by the manufacturer, or as ordered by the Engineer, a tack or prime coat compatible with the membrane system shall be applied according to the manufacturers recommendations.

Membrane

The membrane shall be a single component, hot applied elastomeric material capable of being sprayed or spread to a uniform thickness. After cooling it shall form a tough resilient membrane, well bonded to the concrete surface.

The membrane shall meet the following requirements:

Penetration	ASTM D1190	1.20 cm max., after 48 hrs. room temp. 77°F.
Flow	ASTM D1190	No flow, 72 hrs. at 158°F.
Bond	ASTM D1190	1/4" separation, 3 cycles, 0°F.
Resilience	Fed. Spec. SS-S-200D	50% min., after 48 hrs. room temp. 77°F.
Elongation	Calif. DWR Test Method CL-2	500%. 1/2" per min., 77°F.
Pliability		No cracks when slowly bent at 10°F. over a one inch mandrel.

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REVISION OF SECTION 515
WATERPROOFING MEMBRANE

(1) At the recommended field application temperature, pour the membrane into a release agent or release paper covered mold or container to a depth of 100 ± 10 mils. The mold or container shall be of sufficient size to yield a test specimen 4 in. long by 1 in. wide. Allow the specimen to cool to ambient temperature, remove from mold, trim to proper size, and dust both sides lightly with talc to prevent stickiness. Place the specimen in a + 10° F cold chamber for two hours. While still in the cold chamber bend the specimen 180° over a one inch mandrel. Remove specimen from cold chamber and inspect for cracks.

Preparation of Concrete Deck

The entire deck and the sides of the curb for a height of one inch above the thickness of the HBP overlay shall be free of all foreign material such as dirt, grease, etc. Prior to applying the primer or liquid membrane, all dust and loose material shall be removed from the deck with compressed air. Water shall not be used to clean the deck unless authorized by the Engineer. Any unusually sharp concrete edges on the deck surface which would puncture the membrane shall be corrected in a manner satisfactory to the Engineer prior to application of the membrane.

Weather and Moisture Limitations

Work shall not be done during wet weather conditions, nor when the deck and ambient air temperatures are below 50° F. The deck surface shall be thoroughly dry at the time of the application of the primer or liquid membrane. The membrane shall not be placed until at least 28 days after deck-concrete placement, unless otherwise directed.

Application, Membrane System No. 1

The coal tar primer shall be applied to the cleaned concrete deck along a strip at least 3 feet wide adjacent to the curbs and up the curb face to the height required for the membrane. The primer shall be applied at the rate of approximately one gallon per 100 square feet of surface. The primer shall be applied with squeegee, brush, or other suitable methods and scrubbed into the surface with a stiff bristled broom. The primer shall be allowed to dry for at least 4 hours and shall be dry to the touch before being covered with coal tar emulsion.

Prior to application of coal tar emulsion, the entire contents of each emulsion shipping container shall be transferred into suitable mixing equipment and mixed until a homogenous mixture is produced.

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WATERPROOFING MEMBRANE

The mixing equipment shall be power driven, shall be of sufficient capacity to mix the entire contents of the container or drum in which the material is shipped, and shall be subject to the approval of the engineer. During hot or dry weather, additional water may be blended into the emulsion for workability, in an amount not exceeding 10 percent, by volume, of emulsion used. After mixing, the material shall be continuously agitated until it is applied.

The unprimed concrete shall be water dampened, but puddle free, just prior to application of the coal tar emulsion. The first coat of coal tar emulsion shall be applied to the primed and unprimed concrete surfaces. When the first coat of emulsion is thoroughly dry, a second coat shall be placed. Immediately following the second coat, and before it has dried, the first ply of coated glass fabric shall be laid. As soon as the second coat of emulsion has dried, with the first ply of fabric embedded in it, the third coat of emulsion shall be applied, allowed to dry, and shall be followed by the fourth coat of emulsion. The second ply of coated glass fabric shall be laid in the fourth coat of emulsion before it has dried. When the fourth coat of emulsion has dried, the fifth (final) coat shall be applied.

Each of the first four coats of coal tar emulsion shall be applied at a rate of not less than one gallon per 60 square feet of surface being sealed. The fifth (final) coat shall be applied at a rate of not less than one gallon per 45 sq. ft. of surface being sealed. The rate of application shall be increased as necessary to completely cover each layer of fabric with emulsion at the time of application. The application rate of the emulsion will be determined on the basis of the quantity of coal tar emulsion measured prior to adding water for workability.

The emulsion shall be applied by hand-held equipment.

The first coat of emulsion shall be applied to the area to be sealed and scrubbed into the surface with medium-stiff brooms. Subsequent coats of emulsion shall be brushed as necessary to obtain a uniform rate of application. Each ply of coated glass fabric shall be pressed into the emulsion with brushes or other suitable tools. The final surface of the membrane waterproofing shall be smooth and free of wrinkles, ridges, or humps.

The plies of coated glass fabric shall be laid parallel to the centerline of the bridge roadway, unless otherwise approved by the Engineer. Joints between sheets of fabric in a ply shall be made by lapping the edges of adjacent sheets at least 3 inches. Joints in the second ply shall be offset from the joints in the first ply by approximately 1/2 the width of the plies.

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WATERPROOFING MEMBRANE

The waterproofing membrane shall extend continuously from the deck areas up onto the faces of the curbs to a height of 1 inch above the HBP overlay surface.

At all open joints, expansion joints, and at other joints as ordered, the glass fabric shall be flashed up the joint face to the top of the joint, cut and turned down into the coal tar emulsion.

After the membrane waterproofing has been completed, the membrane shall be cut with 2 right angle cuts at all deck drain pipes.

The cuts shall be made to the inside diameter of the drain pipes, after which the corners of the membrane waterproofing shall be turned down into the drains and laid in a coating of emulsion.

Application, Membrane System No. 2

The primer shall be applied to the cleaned concrete surfaces at the rate and according to the procedure recommended by the membrane manufacturer. All surfaces to be covered by the membrane shall be thoroughly and uniformly coated with primer. Cautionary measures shall be taken to assure that pools and thick layers of primer are not left on the deck surface to scum over. Drying time prior to applying the membrane shall normally be as recommended by the manufacturer, however, membrane shall not be applied until substantially all volatile material has dissipated from the primer. The prefabricated membrane shall be applied to the primed curb and bridge deck surfaces by either hand methods or mechanical applicators. The membrane shall be placed in such manner that a shingling effect will be achieved and that any water which accumulates will drain toward the curb and the drain pipes. Each strip will be overlapped a minimum of 4 inches. An adhesive or a wide tipped torch to cause tackiness shall be used, if necessary, to assure a good seal of the joints. Hand rollers or other satisfactory pressure apparatus shall be used on the applied membrane to assure firm and uniform contact with the primed concrete surfaces. Special care shall be used at the curb face to see that the membrane is uniformly adhered to the concrete. The entire membrane shall be essentially free of wrinkles, air bubbles, and other placement defects. Any torn or cut areas, or narrow overlaps, shall be patched, using a satisfactory adhesive and by placing sections of the membrane over the defective area in such manner that the patch extends at least 6 inches beyond the defect. The patch shall be rolled or firmly pressed onto the surface. Joints and drain pipes shall be protected in a manner similar to that described for System No. 1.

Bubbles larger than approximately 3 inches in diameter which develop after placement of the membrane and before placement of the protective cover shall be punctured, the air expelled, and patched in the manner described above.

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WATERPROOFING MEMBRANE

Application, Membrane System No. 3

Primer, if required, shall be applied in accordance with instructions for primer application of Membrane System No. 2.

Hot membrane shall be applied to the prepared surfaces at a uniform rate to yield a minimum of 90 mils thickness (0.5 gallon per sq. yd. or 2 sq. yd. per gallon). Application temperature, equipment, and procedures recommended by the membrane manufacturer shall be strictly adhered to. Special care shall be exercised, using squeegee or other suitable means, to apply the membrane at the curb to a height one inch above that required for the hot bituminous surfacing overlay. Splattering of membrane or discoloration of the curbing above this point will not be permitted. Small pin holes which may develop in the cooled membrane are not considered detrimental since they re-seal with the application of heat from the bituminous surfacing overlay.

Protection and Overlaying (All Systems)

Vehicles, including mechanical spreaders, shall not be operated on the bare membrane unless otherwise permitted in writing by the Engineer. Following application of the membrane and any required curing, the entire deck surface, from gutter line to gutter line, shall be covered with 65 lb. grade asphalt roll roofing. Not more than one day shall elapse between placement of Membrane Systems No. 1 and No. 2 and placement of the roofing. For Membrane System No. 3, placement of the roofing shall follow the apppication of the membrane within one hour. Roofing shall be laid parallel to the centerline of the bridge, unless otherwise approved. A suitable, compatible mastic or cement shall be used when required to tack the roofing to the membrane surface. The roofing strips shall normally be butted together at both longitudinal and transverse joints. Overlapping shall be kept to a minimum with a maximum allowable overlap of four inches. The maximum allowable space between adjoining sections of roofing shall be three-eighths inch. All overlaps shall be securely bonded with suitable mastic or cement. The entire roofing application shall be essentially free of wrinkles, bubbles and other placement defects. Wrinkles and "fish mouths" rising over one-half inch above the bridge deck, shall be slit and either removed or lapped and cemented together. Following the placement of the roofing, a bead of the hot membrane on System 3, or other suitable mastic on Systems 1 and 2, shall be run along the cove where the curb meets the roofing material. The bead shall fill the void preventing water from entering between the roofing and the membrane.

Only rubber tired vehicles necessary for construction shall be allowed on the roofing material. Public traffic will not be allowed. The Contractor shall be responsible for maintaining the condition of roofing material until covered with pavement. As soon as practical,

following the placement of the asphalt roll roofing, Hot Bituminous Pavement shall be placed in a single lift to the compacted depth required by the plans. The HBP shall be Grading E, unless otherwise specified and shall meet all the applicable requirements of Section 403 except as modified herein.

A tack or prime coat shall not be used on the top surface of the asphalt roll roofing. The HBP shall be dumped directly into the lay-down machine hopper. After filling the hopper, the truck shall pull forward and shall not be in contact with the lay-down machine while it is moving. Dumping the mixture onto the deck ahead of the lay-down machine will not be permitted. The HBP shall be spread and rolled in such a manner that the membrane and roofing will not be damaged. The minimum temperature of the HBP at the time compaction begins shall be 235° F. To assure this temperature, the mixing discharge temperature may be up to 30° F higher than would otherwise be permitted. The use of vibratory rollers, with the vibrator on, will not be permitted. A minimum percent compaction is not specified, however compaction shall be accomplished to the satisfaction of the Engineer.

Measuring Waterproofing Effectiveness

After completion of the overlay, the waterproofing effectiveness of the membrane-pavement system shall be determined. The minimum electrical resistance shall be 500,000 ohms when tested in accordance with Colorado Procedure 62. Testing shall be done at a time when the pavement is essentially free of moisture from rainfall or rolling operation. Areas designated by the Engineer as having a lower resistance reading than 500,000 ohms shall be repaired at the Contractor's expense by removing the pavement and then replacing or repairing the defective membrane. HBP shall then be placed in a manner that will yield a neat appearing, smooth riding pavement. If more than 30 percent of the bridge deck area is defective as shown by tests, the Engineer may require the entire bituminous pavement overlay and membrane removed and the deck cleaned in a satisfactory manner. The entire membrane-pavement system shall then be replaced according to specifications.

METHOD OF MEASUREMENT

Waterproofing membrane including asphalt roll roofing, complete in place and accepted, will be measured by the number of square yards of bridge deck covered. Material placed on curb faces will not be measured.

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REVISION OF SECTION 515
WATERPROOFING MEMBRANE

BASIS OF PAYMENT

Waterproofing membrane including asphalt roll roofing, will be paid for at the contract unit price per square yard. Payment will be made under:

Pay Item	Pay Unit
Waterproofing (Membrane)	Square Yard

Hot Bituminous Pavement will be measured and paid for in accordance with Section 403.

EXHIBIT 3

COLORADO DIVISION OF HIGHWAYS

CONDITIONS FOR APPROVAL OF WATERPROOFING
MEMBRANE FOR CONCRETE BRIDGE DECKS

Manufacturers of membrane systems seeking approval, by the Division, for their product under the latest revision of Section 515, of the Standard Specifications are requested to follow the procedures as outlined herein.

1. The manufacturer shall submit to the Division of Highways Materials Laboratory, 4340 E. Louisiana Ave., Denver, Colo., the following:

   A. Technical data on primer and membrane for prefabricated systems or components of fabricated in place systems, including composition, thickness, test methods, and results.

   B. Instructions for application of primer and membrane or components including rate of primer application, length of curing, recommended temperatures for placing membrane on the deck, and temperature of asphaltic pavement when placed on membrane.

   C. A one quart sample of primer and a sample of the membrane measuring a minimum of 12 in. by 48 in. or a sufficient quantity of components for fabricated in place systems to make 4 sq. ft.

2. Contingent on a satisfactory evaluation by the Materials Laboratory, the manufacturer (or supplier) may contact contractors having or bidding on highway contracts in which this item is involved. However, the manufacturer and contractors shall be aware that the laboratory evaluation alone does not constitute approval of the product. The contractor shall be informed by the manufacturer that the Division will allow the trial use of the membrane system subject to the following conditions:

   A. The contractor shall obtain written permission for use of the product as required by the revision of Section 515.

   B. The trial application shall be limited to one structure only and in case of more than one structure on the project, the one having the least area shall be used.

   C. The manufacturer or supplier shall give the technical assistance necessary to insure the membrane is applied in accordance with their requirements.

D. Samples of primer and membrane or components delivered to the project may be taken by the Engineer for laboratory evaluation.

3. Upon completion of the membrane system and before placement of the hot bituminous pavement, it shall be inspected by the Engineer for practicality of construction techniques. The inspection shall also include the determination of the membranes' electrical resistance, using the equipment described in Colorado Procedure 62, when required by the Engineer. Hot bituminous pavement will be placed on the membrane only after satisfactory inspection results.

Final approval will be subject to the results of Colorado Test Procedure 62 for measuring the waterproofing effectiveness of membrane-pavement systems and the Engineers' evaluation of the practicality of construction techniques.

If approved, the membrane system will be considered as a substantially equal system for future highway contracts.

EXHIBIT 4

COLORADO PROCEDURE 62-72

FOR MEASURING WATERPROOFING EFFECTIVENESS OF MEMBRANE-PAVEMENT SYSTEMS

SCOPE

1.1 This method describes the procedure for determining the waterproofing effectiveness of membrane-pavement systems as applied to bridge decks. The tests are to be performed on the asphalt pavement overlay surface covering the waterproofing membrane.

APPARATUS

2.1 Ohmmeter, 20,000 ohms per volt rating.

2.2 No. 18 insulated wire, Belden test probe wire or equivalent, two spools, 125 ft each, with connectors.

2.3 Copper plate, 12 in. x 12 in. x 1/8 in., with clips for connecting the ohmmeter and means to connect a 36 in. wooden handle.

2.4 Polyurethane sponge, 12 in. x 12 in. x 1/2 in. to be attached to the copper plate by rubber bands.

2.5 Pressure spray can, 3 gallon capacity.

2.6 Stone cutters chisel, 3/4 in. face.

2.7 Hammer.

REAGENT

3.1 Wetting agent, Aerosol OT manufactured by the American Cyanamid Company.

PROCEDURE

4.1 Prepare surface to be tested by removing all foreign material by sweeping and/or scraping. Do not use water to clean. Surface must be dry and clean before testing.

4.2 Divide bridge deck into workable sub-areas similar to that illustrated in Figure 1. If the bridge is to be kept open to traffic, it is advisable to mark and test one lane at a time. Locate a reinforcing bar or other connection to the reinforcing steel in the bridge deck. A positive connection to the top mat of the reinforcing steel is desirable; however, if this is not feasible, the bridge railing, expansion joints, light standards, drainage scuppers, or other exposed steel may provide a positive connection to the reinforcing steel.

LAYOUT FOR TEST GRID

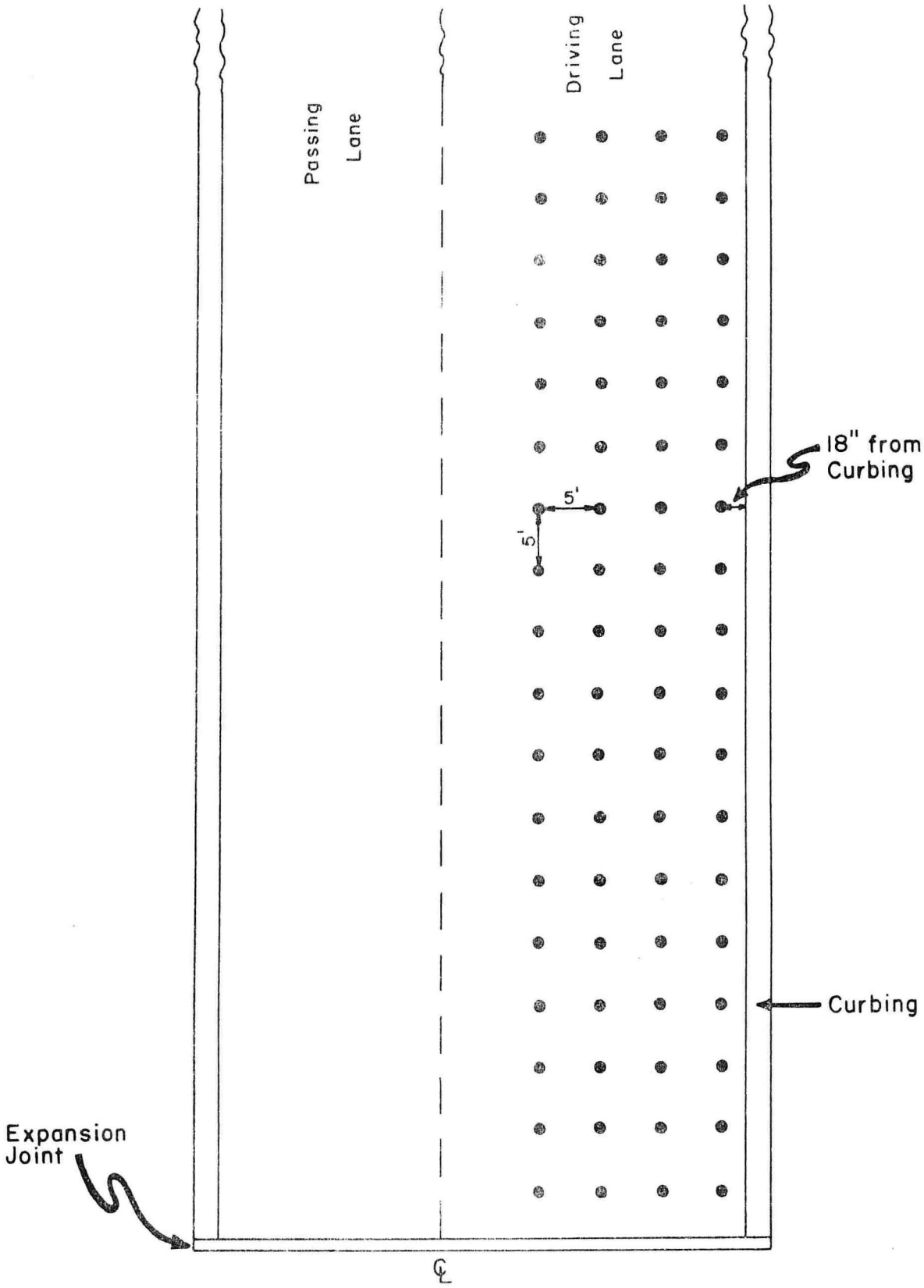

FIGURE 1

EXHIBIT 4

TYPICAL RESISTANCE VALUES

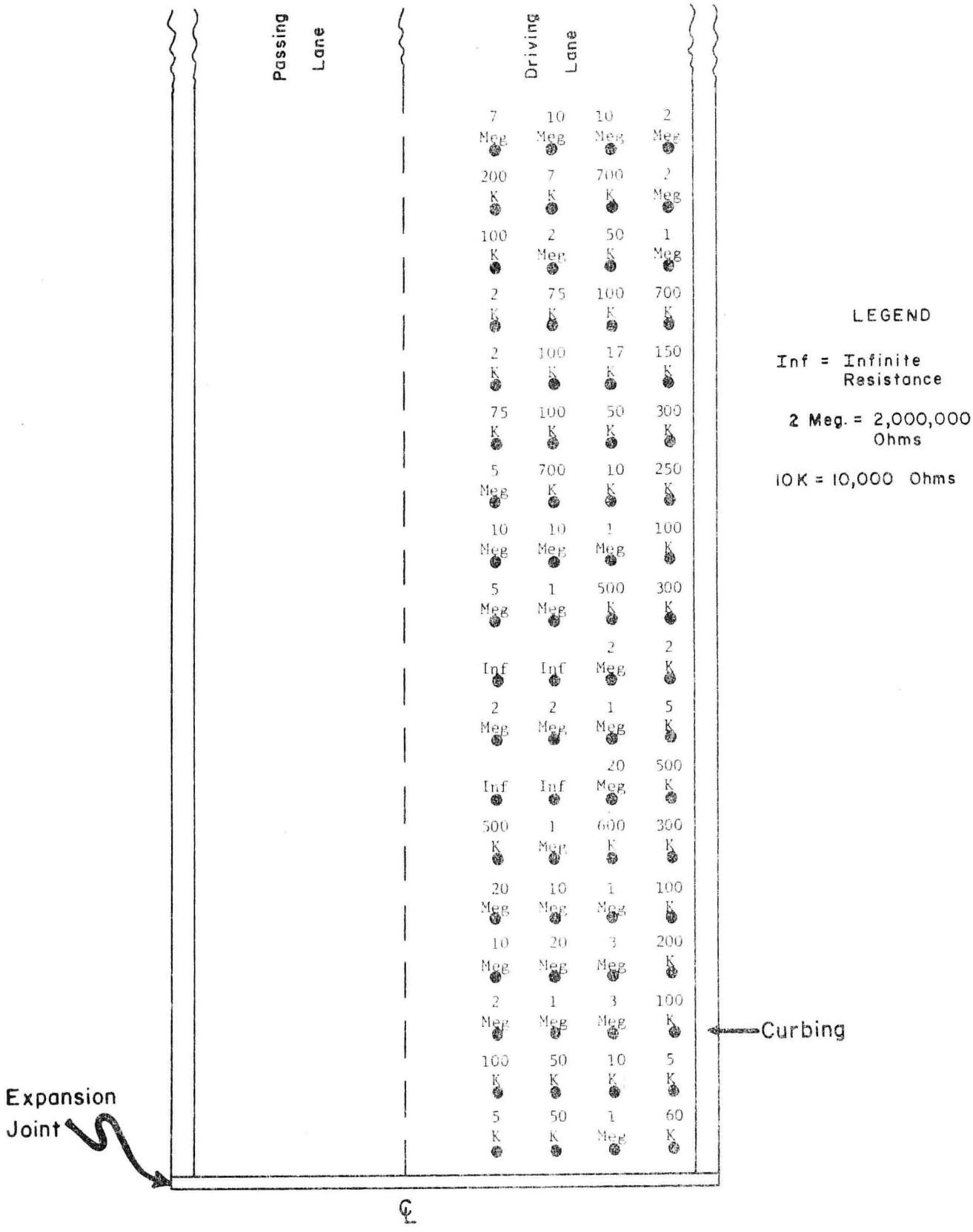

FIGURE 2